KOREAN RESEARCH AND APPLICATIONS OF FRP IN BRIDGES

Byung-Suk KIM [1] Jeong-Rae CHO [1] Sung Yong PARK [1]

[1] Korea Institute of Construction Technology, Goyang, Gyeonggi, Korea (South)

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1 INTRODUCTION

Besides its exceptional resistance to corrosion, Fibre Reinforced Polymers (FRP) present the advantage to develop high strength compared to its self-weight which highlighted it recently as a material that can replace fairly classical construction materials like steel and concrete. The emergence of glass fiber and the development of resin fabrication technology made it possible to reduce significantly the costs of FRP material and the emphasis given on the importance of lifecycle cost (LCC) for structures after the 1980s opened its exploitation in the construction domain.

About 42% of the 575,000 bridges constituting the American bridge stock is requiring repair or strengthening. Surveys revealed that the main cause of their degradation is the corrosion of rebar. Accordingly, the 10 years-term CONMAT (CONstruction MATerial) Program has been launched in 1995 to rehabilitate such social infrastructures with a budget of 2 billion dollars, of which 40% has been invested in domains applying FRP on bridge structures. This investment aimed to develop the next generation of bridge systems presenting improved durability and reduced LCC. The first FRP deck was built in 1996 in USA and, 32 bridges were applying bridge system using FRP in the late 2000. Moreover, the IBRC (Innovative Bridge Research & Construction) Program launched in 1998 is supporting financially structures making use of materials like FRP, HPS (High Performance Steel) and HPC (High Performance Concrete) [1].

Keller reported that the utilization of FRP sheets for repair and strengthening purposes in Japan increased by three times in 1996 compared to 1995, immediately after the Kobe earthquake and that efforts are continuously exerted to reduce LCC of structures. 1) After the issue of the "Roadmap for the reduction of construction costs of public works" by the Japanese Ministry of Land, Infrastructure and Transport (MLIT) in 1994, the "Development of technologies using innovative materials for construction" has been launched as a global technology R&D project of the Ministry of Construction and Transportation which resulted in the publication of the "Guideline for measures reducing the construction costs in public works" in 1997 focusing on the reduction of initial construction costs. Succeeding R&D were continuously promoted and led to the release of the "New guideline for measures reducing the construction costs in public works" in 2000 including cost reduction through shortening of construction term, reduction of LCC and, reduction of social costs. Finally, the "Program for the structural reform of public work costs" has been drafted in 2003. Actually, this new guideline is under revision and supplementation and, researches to implement evaluation and management of cost reduction effects are performed jointly by the Japanese National Institute for Land and Infrastructure Management of MLIT, the Japanese Public Works Research Institute and the Japanese Building Research Institute. The draft of the next "Program for the structural reform of public work costs" is expected in 2007.

Canada is performing researches for the improvement of durability in bridges applying FRP rebar and tendon as well as for the development of steel free deck since 1995 through ISIS (Intelligent Sensing for Innovative Structures), a consortium-shaped research center. On the other hand, Europe began researches on FRP since 1960 and has established standard guidelines relative to the design, fabrication and construction of FRP structures in 1996. The Eurocrete Project started in 1993 is currently conducting investigations to clarify the durability of FRP as well as the establishment of design codes for Fibre Reinforced Concrete (FRC). In addition, the Fiberline Company has been founded in partnership with Denmark, United Kingdom, Sweden, Netherlands and Spain. The company developed the ASSET System, a pultruded bridge deck composed by the combination of 2 triangles, which has been actually applied effectively on the West Mill Bridge in England.

The rapid urbanization and industrialization of Korea led among others to the strengthening of the road network. Especially, the bridge stock recognized a sudden increase since the mid of 1990s, to be constituted currently, as of December 31, 2005, by 22,871 bridges developing a total length of 1,987 km [2]. According to the data of the Korea National Statistical Office, the volume of orders in the

Korean bridge construction market reaches annually an amount of 2.4 trillion won [3]. As requirements for improved durability, reduced maintenance costs, accelerated construction in urban areas, seismic strengthening of non-seismically designed piers are being stressed according to the rapid industrialization and urbanization, and emphasis is given on special features of FRP like high durability, lightweight, high strength and prefabrication, R&D have been actively conducted since 2000 to exploit FRP on bridge structures. The FRP industry in Korea has been originated from military industry, and the FRP application in construction is started for the repair and strengthening of degraded structures. R&D began in the 2000s on FRP deck, FRP tendon, and hybrid bridge systems like FRP-concrete composite decks and concrete filled FRP composite columns. This paper focuses on the bridge domain among the diversified fields of FRP and addresses the status of the relevant industry and the analysis of the technological trends in Korea. Prospects of the exploitation of FRP in the construction domain are also examined.

2 OVERVIEW OF KOREAN RESEARCHES AND APPLICATIONS OF FRP IN BRIDGE

Except for carbon fiber, most of FRP materials like glass fiber and various matrices are produced and sold in Korea. Carbon fibers were formerly produced but are now exclusively imported for payability reasons. FRP products like GFRP sheet, GFRP rebar/grid, CFRP plate for construction purpose are produced and available for sale (Figure 1, 2, 3). Moreover, custom made deck panel obtained by pultrusion and marine pile obtained through filament winding manufacturing process are also fabricated for construction purposes (Figure 4). Since FRP industry in Korea has been originated from military industry, the overall conditions like fabrication techniques have already reached an advanced level. Even if it is delicate to give precise calculation of the scale of the market related to glass fiber in Korea, a survey of the listed companies reveals that the market scale reached approximately 291 billion KRW in 2000 and increased to 340 billion KRW in 2004. The market of resin also appears to be similar in view of the utilization rate of resin regard to glass fiber. The very first applications of FRP in construction were essentially found in the repair and strengthening of deteriorated structures. The market scale of repair o strengthening of degraded structures is estimated to run around 350 billion KRW in 2004. In the domain of bridge structures, R&D started with FRP decks in the early 2000s to extend effectively the scope of applications with FRP tendon and hybrid bridge systems like FRP-concrete composite decks and concrete filled FRP composite columns.

The distinctive feature of R&D in Korea is that R&D is performed under governmental leadership. Most of the researches are led essentially to develop products. The most representative and comprehensive R&D currently under course is "BRIDGE 200" (2002~2006) performed since 2002 by the Korea Institute of Construction Technology (KICT) and targeting the development of technologies for the extension of the lifecycle of bridge structures. The project involves the development of FRP decks, FRP-concrete composite decks, strengthening techniques using FRP and, fiber reinforced concrete. As a recent national research program, the "Development of technologies using innovative materials for the next generation of facilities" project (2005~2010) is implementing researches to develop hybrid structures combining FRP and existing construction materials (investment of about 6 billion KRW among the 21 billion KRW of the total project scale).

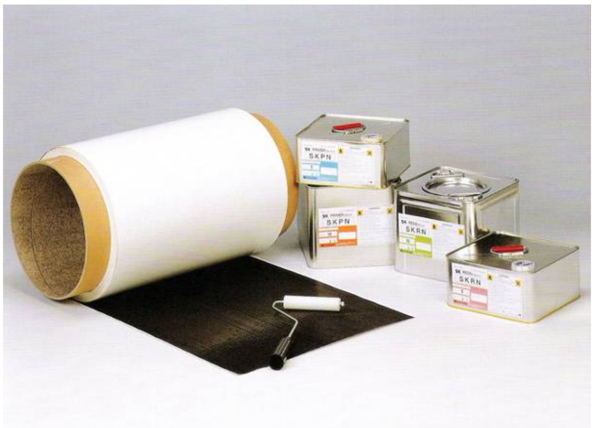

Fig. 1 GFRP sheet

Fig. 2 CFRP plate

Fig. 3 GFRP rebar

Fig. 4 Pultrusion of deck panel

3 TECHNICAL TRENDS

3.1 Strengthening and Rehabilitation of Bridge

To date, strengthening techniques for flexural members in structures were mainly using external bonding of CFRP strip or sheet. Recently, near surface mounted reinforcement proceeding by embedding plate or rod-shape reinforcements in notches cut on the surface and external stressing using FRP tendon have been developed. As a part of the "BRIDGE 200" project, KICT is carrying out researches for the development of strengthening methods using innovative near surface mounted reinforcement and external stressing. The developed near surface mounted reinforcement is improving the bonding performance and constructability of strengthening by embedding a T-shape plate fabricated by means of bi-directional layers of carbon fibers and glass fibers (Figure 5, 6). The external stressing method under development is fixing the CFRP plate using a wedge-type mechanical anchor and with external stressing (Figure 7). The anchor has been specially designed to maximize at the most the performance of the CFRP plate currently used as reinforcement and, is actually variously tested (Figure 8). Despite the costliness of FRP material in the former external stressing method as well as the fact that failure occurred through debonding at 30~60% of the ultimate strain of FRP, the external stressing method is seen to bear remarkable applicability since it is able to exploit the ultimate failure strain of the CFRP plate [4].

On the other hand, seismic strengthening technique for piers using FRP wrapping automation device is under development (Figure 9, 10). The feature of this technique is that wrapping is done after glass fiber has been glued with resin using an automation device. Since this process secures the continuity of the fiber, the confinement stress can be effectively applied. This technique has been applied in the design of two bridges to be constructed that are Seomjin Bridge located on a national highway and a bridge situated on the 88 expressway.

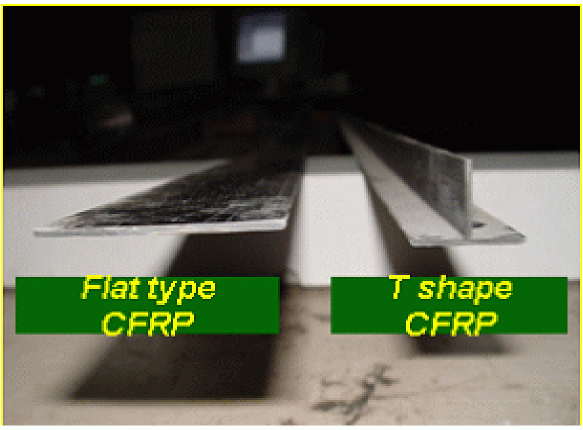

Fig. 5 Bi-directional CFRP plate

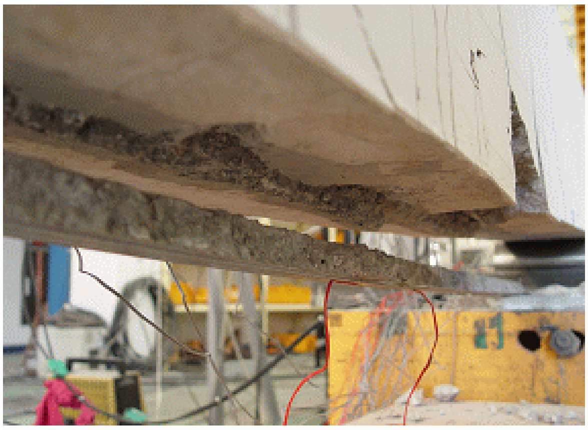

Fig. 6 Near surface mounted method using

T-shape CFRP plate

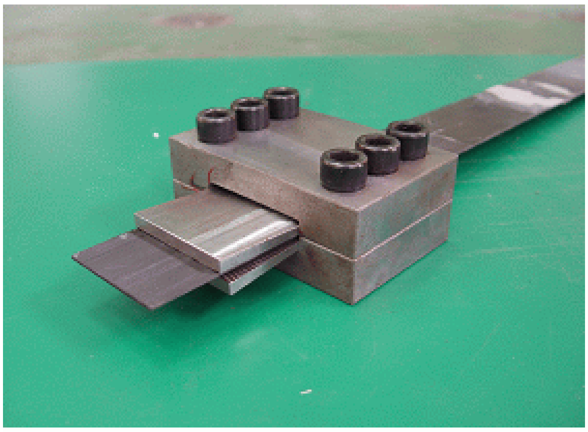

Fig. 7 Wedge-type mechanical anchor for CFRP plate

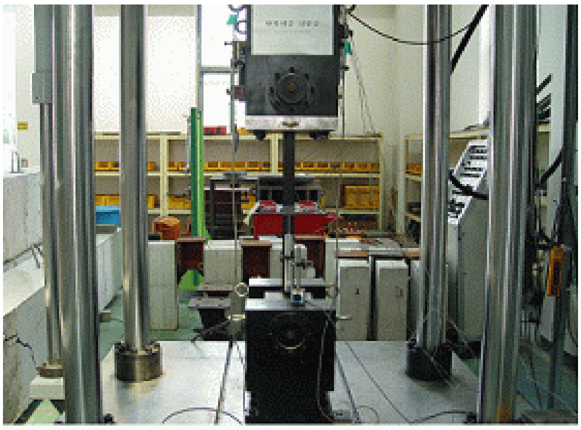

Fig. 8 Test of mechanical anchor

Fig. 9 FRP wrapping automation device

Fig. 10 Field test of FRP wrapping automation device

3.2 FRP Rebar and Tendon

FRP rebar has been developed for repair and strengthening purposes and, is already available for sale on the market. FRP rebar that can be use for newly built structures is currently under development through a national R&D program performed by KICT and Dongwon Construction Ltd. (Figure 11, 12). The GFRP reinforcing bar developed in this study is composed of E-glass and vinylester, and is manufactured through a process combining braiding and pultrusion for the molding of deformation. The performances of the developed rebar were evaluated by means of tension, bonding and burn-out tests and, SEM photography. These tests revealed that the GFRP rebar develops tensile strength larger than 1,000MPa, elastic modulus exceeding 57GPa, and bond strength higher than 24MPa. These results are outstanding considering that the bond strength increases by approximately 20% and the tensile strength by more than 40% compared to the former product [5].

In addition, KICT also recently launched another research program "Development of FRP tendon, and its anchorage system and application technologies" (2005~2008) to develop and apply FRP tendon.

Fig. 11 Braiding of FRP rebar

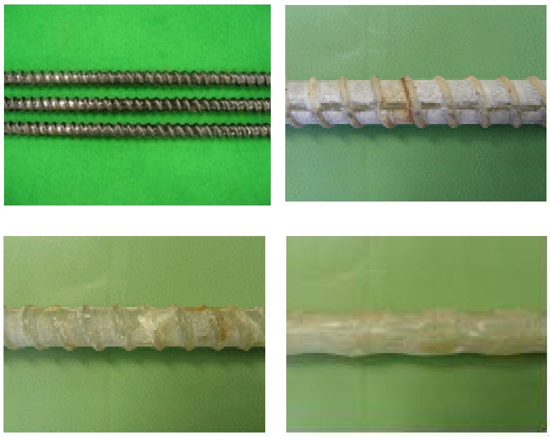

Fig. 12 Various FRP rebar specimens

3.3 FRP Deck

Among the members constituting a bridge system, the member offering relatively the most favorable applicability for FRP is FRP deck. Kookmin Composite Infrastructure (KCI) Ltd. and KICT developed jointly the Delta Deck from 2001 to 2004 (Figure 13). After the trial application of the Delta Deck on the Beoncheon Bridge in 2001, the deck has been applied on Hyeongju Bridge and Biwoodang Bridge, and the largest application in the world is previewed for Nulcha Bridge with a length of 300 m of which construction is expected to begin in 2006 (Table 1, Figure 15, 16, 17). Recently, KCI developed the snap-fit FRP deck enhancing the constructability of such deck (Figure 14). This deck is composed by prefabricated precast panels obtained by pultrusion, which are assembled on field through precast snap-fit-type mechanism. These panels can be disassembled and reused [6].

Table 1 FRP Decks in Korea

Bridge designation	Location	Completion year	Length (m)	Width (m)	Remarks
Beoncheon	Jungbu expressway	2001.4	8	4	Steel plate girder
Hyeongju	Gyeonbu expressway	2002.12	11	4.3	Steel plate girder
Biwoodang	Cheonggye stream, Seoul	2004.6	44.5	9	Steel plate girder
Gaejeong	Jangsu District, Province of Jeonbuk	2005.3	25	11	Steel plate girder
Access bridge of Gwangyang Harbor	Gwangyang Harbor	2004.11	150	10.9	Steel plate girder
Access bridge of Pyungtaek Harbor	Pyungtaek Harbor	2005.4	70.14	11.9	PSC girder
Malmoo	Busan	Late of 2006 *	120	30	Steel box girder
Nulcha	Busan	Early of 2006 *	300	35	RC girder (the largest in the world)

* Expected construction start

On the other hand, a complete FRP composite bridge has been constructed in 2002 on the provincial road of Yeongweol in the Province of Gyunbuk using hand-layup method according to the research performed jointly by Daewon Science College, Sungwon Construction Co. Ltd. and WonChang Entec Co. Ltd. (Figure 18). The bridge is actually under operation.

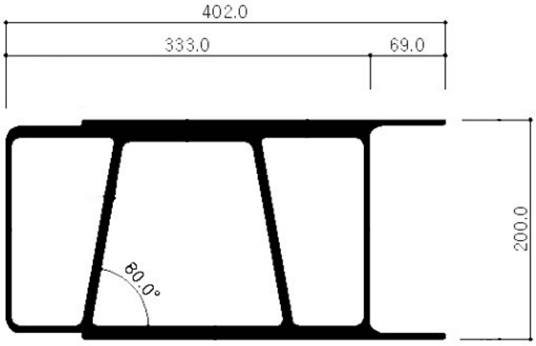

Fig. 13 Delta Deck

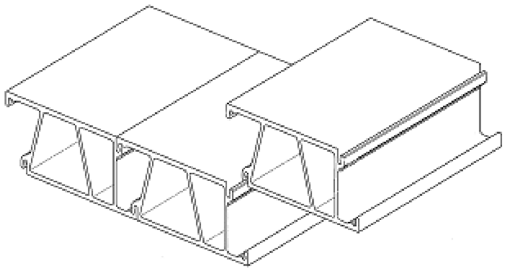

Fig. 14 Snap-fit FRP deck

Fig. 15 Beoncheon Bridge

Fig. 16 Biwoodang Bridge

Fig. 17 Gwanghyang Harbor Bridge

Fig. 18 Provincial road of Yeongweol - Gyunbuk (Composite material bridge)

Besides, research has also been conducted on a FRP deck with hollow rectangular section as part of the project "BRIDGE 200" (2002-2006) of the Korea Institute of Construction Technology. In order to establish design specifications of FRP decks, this research performed diversified studies like static/fatigue performance test, durability performance evaluation and bridge subcomponents, considering optimum design method, structural analysis, fabrication technique (pultrusion) and the materials (Glass fiber/Vinyl Ester or Polyester resins). Figure 19 and Figure 20 illustrate respectively the chemical resistance test and fatigue test of FRP material. Figure 21 shows a view of the wheel rolling test performed on a bridge deck pavement developed for the FRP deck. Figure 22 pictures the performance test for a parapet installed on the FRP deck [7].

Fig. 19 Chemical resistance test

Fig. 20 Fatigue test of FRP material

Fig. 21 Wheel rolling test of bridge pavement for FRP deck

Fig. 22 Performance test of parapet

3.4 FRP-Concrete Composite Deck

Efforts on hybrid structure are recently exerted to combine FRP with traditional construction materials that are concrete and steel so as to take selectively advantages of the merits of each material. As one of these efforts, FRP-concrete composite decks is developed under the "BRIDGE 200" project (2002~2006) of KICT, of which practicability has been established as a target of the research started and conducted by the national R&D program "Development of technologies using innovative materials for the next generation of facilities" (2005~2010).

FRP-concrete composite decks are manufactured by pouring concrete on GFRP panels fabricated through pultrusion. During the manufacture, the GFRP panels disposed at the bottom play the role of form (or mould) and, in service, the panels are used as main tensile members (Figure 23, 24). The concrete poured at the top performs as compressive member. The sectional shape has been improved through diversified analyses and tests. Especially, sand coating and perforated FRP rib shear connector are introduced to achieve the composition of FRP and concrete. Fatigue endurance is currently under course by means of wheel rolling test (Figure 25). A trial construction in a temporary bridge and field test are previewed in November of 2006. On the other hand, researches are also conducted to introduce precasting in the developed deck [8].

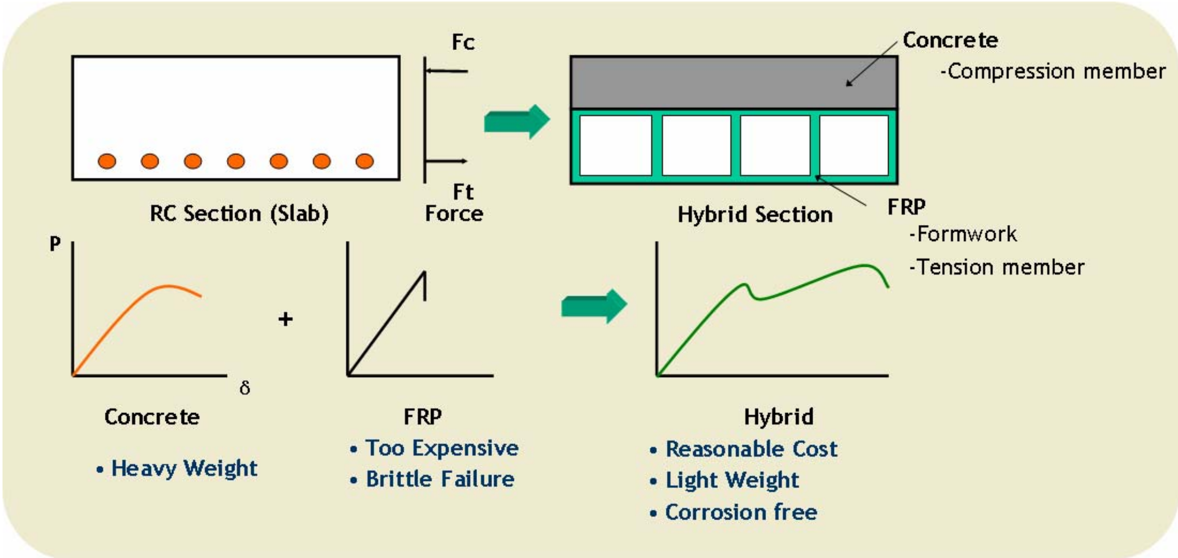

Fig. 23 Basic Idea of FRP-Concrete Composite Deck

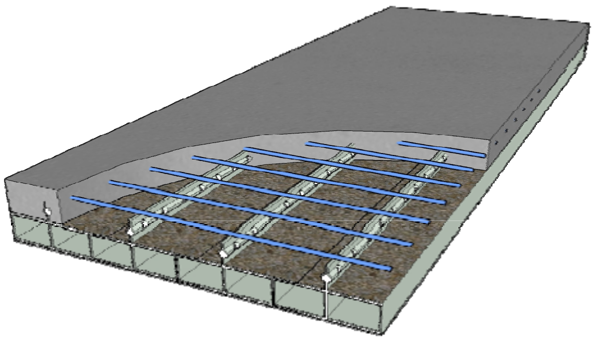

Fig. 24 FRP-Concrete composite deck

Fig. 25 Moving wheel load test of FRP-Concrete composite deck

3.5 Concrete Filled FRP Composite Column

As another hybrid structure using FRP and concrete, concrete filled FRP composite columns are being developed as a part of the national R&D program "Development of technologies using innovative materials for the next generation of facilities" (2005~2010). The target of the developed column system is small to medium scale bridges for which accelerated construction is required and for which the overhead clearance is limited like bridges located in urban areas.

These columns are fabricated by filling FRP tubes with concrete, which are playing the role of mould as well as retaining concrete. The fabrication methods under development are cast-in-place and precast methods (Figure. 26). In the figure, the first pier is a CFFT (Concrete Filled FRP Tube) pier with cast-in-place concrete, where FRP is used as mould and replaces the transverse steel reinforcing bars. The second pier is a precast CFFT adopting FRP instead of transverse steel reinforcement. In the case of the cast-in-place CFFT pier, the FRP tube was manufactured at first to be used as mold and to replace the transverse steel reinforcement. Concrete was then cast-in-place to complete the pier. For the precast CFFT pier, modules with definite dimensions were produced in shops prior to be assembled on site. Both types of piers exhibited enhanced compressive strength according to the increase of the core confining pressure. Moreover, significant shortening of the construction time was realized since construction could be performed without fabricating the moulds, which represents a remarkable benefit in terms of indirect social costs, especially in heavy traffic zones like urban areas. Currently, some tests of mechanical properties of GFRP tube made by filament winding was performed and manuafacturing device is designed.

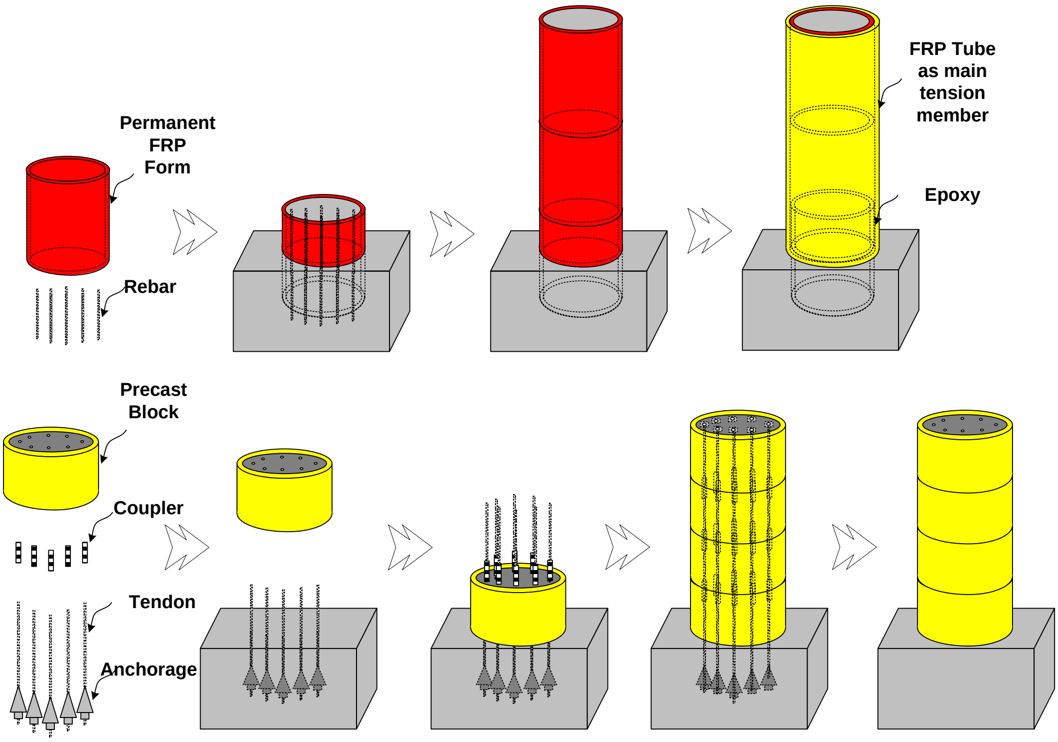

Fig. 26 Concrete filled FRP composite column

4 PROSPECTS AND CONCLUSIONS

In Korea, technologies exploiting FRP in construction domain are still in their early age of research and application. This situation can be explained by the relatively high costs of FRP compared to other construction materials and the lack of researches concerning application technologies of FRP. However, promising prospects for the exploitation of FRP in construction domain and for the improvement of the relevant technological level can be expected in view of several technical as well as economical factors. The first factor is the rising importance of LCC considering maintenance costs of structures. The second factor is the relatively more favorable circumstances of the supply and demand of FRP materials in Korea. The third factor is the early efforts exerted domestically to exploit FRP in the construction domain. However, a major issue for the growth of the technological level is undoubtedly the need for continuous efforts to develop and establish criteria and specifications relevant to the use of FRP.

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